K. Bell

# THEORY AND EXPERIMENT:

## A LECTURE

DELIVERED BEFORE THE

BOARD OF ARTS AND MANUFACTURES FOR LOWER CANADA,

On the connection between Experiment and Theory in the Progress of Scientific Discovery.

DECEMBER 20, 1858.

BY

REV. E. K. KENDALL, B.A.,

SCHOLAR OF ST. JOHN'S COLLEGE, CAMBRIDGE, AND PROFESSOR OF MATHEMATICS IN THE UNIVERSITY OF TRINITY COLLEGE, TORONTO.

Printed by Request.

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# PREFACE.

In complying with the request that I would allow the following Lecture, delivered before the Board of Arts and Manufactures for Lower Canada, to be printed for more general circulation, I have but to remark that it was prepared in answer to a call from the Society for a Lecture in Physical Science or Mechanics at a time when my professional duties left but small leisure at my command. If my object had been to prepare a treatise for publication the form would have been very different; but I have preferred printing the lecture, with but a few verbal alterations, as it was delivered, to making extensive changes either in arrangement or illustration.

It is almost superfluous to acknowledge obligations, both for argument and illustration, to "Whewell's History of the Inductive Sciences," "Herschel's Natural Philosophy," and other works of similar character; obligations, however, which I have endeavoured as far as possible to acknowledge in the marginal notes.

It will be observed, that, for the sake of simplicity, I have not thought it requisite to distinguish between "Theory" in the sense of a *proved hypothesis*, and "Theory" carried out into its inevitable consequences; and in a similar manner I have not always drawn a line of distinction between Practice, Experience, and the systematic experience (if one may be allowed the term) which we call Experiment.

Montreal, January 6th, 1859.

# LECTURE.

Ladies and Gentlemen,—In inviting your attention this evening to the subject on which I have proposed to lecture, I think we shall at least agree in this, that if properly treated of, it would be a most important and very interesting one. The difficulty of handling such a subject satisfactorily, lies not in the poverty but in the exuberance of the material; in determining precisely what points will be the most interesting and profitable to touch upon, when there are so many interesting and profitable topics open to our choice; and still more in attempting to convey anything of scientific truth without using hard words and ugly calculations—from the former, I am afraid we shall hardly escape altogether, though I shall do my best to explain some of the more important ones, and if on some points our explanations should seem vague and unsatisfactory, I must, in claiming your indulgence for

the same, remind you that the aforesaid ugly calculations would put many of these difficulties to rights, did our limits admit of their being employed.

The reason why a subject has been selected which is so extensive in its character, co-extensive indeed in its bounds with the domains of all Science of Nature or of Thought, and on account of this vastness so difficult to deal with satisfactorily, is that it seems to be one peculiarly adapted to the spirit of the age we live in and of the people with whom we have to do, and moreover peculiarly suited to a body like the one by which I have been called upon to address you, which may be supposed to consist of those who are interested in the progress of Science, some in a more theoretical, others in a more practical manner.

Reasons for choosing the subject.

Theoretical men and practical men are perhaps rather apt to look on one another with something of suspicion. The practical man is apt to take for granted that Adam Smith's famous definition of a philosopher is a true one, "one who does nothing and speculates about everything," and to look on Philosophers as the drones in the social hive, for whom the working bees have to gather honey. The Philosopher on his side is too apt to undervalue the shrewd good

sense and wisdom which often characterize the practical man, the real Philosophy that there is about him, though he may be somewhat deficient in theoretical knowledge, and to look on him with disfavour as one who picks *his* brains, and applies the results of long study and patient thought to his own uses and advantage, without acknowledgment and without gratitude. It may be well then to a Society like the present to endeavor to shew that such notions where they exist are founded on mistake; that Theory and Practice fit one into the other like hand and glove, that if we would make any real discoveries in Physical Science, a philosophical turn of mind is equally necessary with a practical one, and that although scientific attainments are by no means to be undervalued, and are in many cases not to be dispensed with, yet also a practical man, if he will use eyes and ears, need not despair of sharing in the glory of discoveries which may well merit the epithet *scientific*, even though he may not possess very extensive theoretical knowledge. We will, therefore,

Continually increasing character of knowledge.

commence by tracing how the fountain of knowledge, like the gentle rivulet, diminutive at first, with difficulty avoiding rather than surmounting the stones and rocks of prejudice and misconception,

muddied and clogged with the weeds and grass of imperfect conceptions and undefined ideas, felt its way onwards, little by little, gathering power as it went, its current continually from time to time receiving accessions of strength, as experiment added more and more of the tributary streamlets which fed it, until at last in these days the stones and rocks lie forgotten under its goodly depths, the weeds and grass perplex those only who are content to sail in its shallows, and it rushes on and on with restless might until it will hereafter be lost in the ocean of infinite certainty.

Ideas in Physical Science entirely the result of experience.

We need not perplex ourselves this evening by endeavouring to ascertain whether or no the mind is capable of receiving ideas independently of, or prior to experience, whether we are to consider the senses as the only inlets of ideas, or whether there are truths which would impress themselves on a reflective mind if there were no external suggestion made to it. Certain it is, that the mind can be educated to grasp conceptions of which it was unable, in an earlier stage of development, to form the slightest notion. But whether we must regard these as taught it by a chain of deductive demonstration from some experimentally established truth; or as suggested by some approximate representation of an abstract

conception; or whether they in truth proceed from unconscious recollection of something previously instilled and lost for a time; or whether they sometimes result from a simple approval by the mind of principles or ideas when suggested to it, which nevertheless it could not have found out for itself. Or whether, on the other hand, we must imagine that the mind has a power of gaining new ideas as it goes along, evolving them for itself from the nature of things, or from its own constitution as it acquires strength and facility, like the athlete, whose limbs have grown supple and strong by exercise, and finds ever new and new ways of shewing his dexterity and vigour. Whether any or all of these be more or less modes in which the mind is enabled to grasp ideas, will not much concern those who, like ourselves, are to confine their attention entirely to science as Nature itself unfolds it; our only Philosophy that which is called Natural Philosophy, our object to trace from the page of History alone, how Theory has been overset or established by practical application; how experimental verification of a *conjecture* paved the way for the establishment of a Theory.

But here we must pause, for several hard words have been made use of already; and of some of these we must attempt to gain some little notion

before we proceed. And first, we must arrive, if possible, at some slight conception of the difference between *Induction* and *Deduction*. We may say roughly that Deduction is the process by which, after we have by any means got at some truths or laws, we *deduce* some other truths from them. Thus if we were to say "All the ancient philosophers set a high value on geometry; Plato was one of the ancient philosophers; therefore, Plato set a high value on geometry," we should *deduce* the fact that Plato valued geometry, from the facts that all the ancient philosophers did so, and that he was one of them. This would be a case of *deduction*. Again—if we were to say, "Children rule women, women rule men, and men rule the world, therefore children rule the world," we should have another case of deduction, which depends for its truth or falsehood on the precise meaning of the words used, and the truths of the successive facts employed.

Difference between Induction and Deduction.

Examples of Deduction.

But these instances shew that something more than deduction is required to establish truth. How do we know that all the old philosophers valued geometry? How do we know that children rule women? The process by which a law is established, by collection and compari-

son of particular instances, is called *induction.* Thus, to shew that all the old philosophers valued geometry, we must collect the names of all the ancient philosophers, and shew that each of them valued geometry: this would be *induction.* To shew that children rule women would be a still harder matter; but, if we could establish the fact, it would be by an inductive process. We must shew that in all parts of the world, or whatever is meant by the world, the women were ruled by the children, and we should find it necessary to divest the word *rule* of its vagueness by some definitions or restrictions. Still greater care would be required if we followed up the other facts asserted. But this introduces us to a difficulty. It is impossible in most cases to collect every instance that may occur: before we rashly conclude the truth of a law from induction, we must collect our instances carefully with a view of ascertaining whether there may not be contradictions of the law, and how far such instances will suffice to overset it. Lord Macaulay, in his essay on Bacon, has furnished an amusing instance of a false induction that will serve to illustrate this part of the subject. The question is proposed, to prove that the origin of the prevalence of Jacobinism, was

Examples of Induction.

Care necessary in performing an induction.

the practice of having three names. Thus, on one side might be ranged Jacobinical possessors of three names: Charles James Fox, Richard Brinsley Sheridan, John Horne Tooke, John Philpott Curran, Samuel Taylor Coleridge, Theobald Wolfe Tone. These were Jacobins. Again those with two names were not: William Pitt, John Scott, William Windham, Samuel Horsley, Henry Dundas, Edmund Burke. For collateral arguments; the practice of giving children three names is a growing practice, and Jacobinism has been growing.—Three names are more common in the United States than in England; the United States is a Republic: we are a Monarchy. Again, one out of each class (Burke and Tone) is an Irishman; therefore being an Irishman is not the cause of being a Jacobin. Horsley and Horne Tooke are both clergymen, therefore being a clergyman is not the cause of being a Jacobin. Fox and Windham were Oxford men, Pitt and Horne Cambridge men, therefore education at Oxford or Cambridge was not the cause of Jacobinism. And yet the conclusion is nonsensical, for one instance will overthrow it—Tom Paine, and William Wyndham Grenville, are sufficient to do the work. Thus, then, care is required in performing an induction in order to arrive at a right conclusion. The inductive method, you

will perceive, is one that we use every day of our lives, without knowing it; some are led by it to truth, some to error; we expect by it to raise corn when it is sown, and not potatoes; we expect the changes of day and night, the cold of winter and the heat of summer, rather because it has always happened so before, than because we know the reason of the changes. Let us take another instance of every-day induction, of a somewhat whimsical character, furnished by Macaulay: "A plain man finds his stomach out of order, and satisfies himself that minced pies have done the mischief. I ate minced pies on Monday and Wednesday, and was kept awake by indigestion all night. I did not eat any on Tuesday and Friday, and was quite well. I ate very sparingly of them on Sunday, and was slightly indisposed in the evening. But on Christmas day I almost dined on them, and was so ill that I was in great danger. It cannot have been the brandy I took with them, for I have drunk brandy daily for years without being the worse for it." He therefore concludes that minced pies do not agree with him. This is an instance of somewhat loose, but yet under the circumstances tolerably satisfactory, reasoning from induction. I hope that now you will have some kind of notion of the difference between

deduction and induction, when the words are made use of. There are certain branches of knowledge which appeal to reason rather than to experiment, the necessary previous induction being of the simplest kind, they are called *deductive sciences.* Of this class is geometry, and also more or less all the various branches of purely Mathematical analysis. Starting from some simple conceptions, nothing more is required than a connected and systematic course of reasoning to establish the various truths which are presented to the mind for acceptance.

Early appreciation of deductive process.

It is, perhaps, owing to the perfection in early times of the first of these namely, geometry, that many mistakes were made, and much of the difficulty arose to which Philosophers were at first subject, and which prevented their adopting a sound method of making discoveries in Physical Science. The system of geometry was so perfect, and so beautiful, that men were led to think that all other knowledge could be acquired in a similar way. It commenced with the simplest self evident theorems, such as "the whole is greater than its part;"—with the simplest problems, such as "let it be granted that a straight line may be drawn from any one point in a plane to any other point;"—with the simplest possible conceptions

such as, "a line is length without breadth." From these a system of geometry was deduced, proposition after proposition, in a most satisfactory and elegant manner, which admits of few improvements even at the present day. The Science is an abstract one, a line and a point are things which can be conceived but not really represented, since it is practically impossible to make length without breadth, but having gained notions of space and dimension, the mind is enabled to perform the various deductive steps of the Science, by the aid of approximate representations, geometrical figures which suggested the idea intended to be represented.

Early love of knowledge for its own sake.

The science thus built up was most highly prized, and that not so much for its practical use, as its intrinsic beauty. Men early perceived that they were gifted with intellects which raised them immeasurably above the other objects of creation; they felt that the exercise of reason was the peculiar prerogative of their nature, and moreover, that it was something more than merely a means to an end, an untainted pleasure, a source of delight. There was a consciousness within them of noble faculties, capable of development and expansion, of creating sciences, of realizing even abstractions of the in-

tellect which have no correlative existence in nature. But this worshipping of intellect led to its own peculiar dangers and mistakes, men were led to undervalue the noble end of tracing laws and operations which directed the course of nature, or which ministered to the necessities of man; they longed to reduce all science to a kind of extended geometry, or at least to a series of deductions from laws not only simple, but self-evident. The motto of one of the most famous of the early Philosophers, written over his cell, "Let no one enter who is not a geometrician," will furnish an example of the temper of mind of those who longed to discover in the laws of nature and of thought, the geometric method; to reduce all the fundamentals of knowledge to simple principles from which phenomena were to be explained by simple application or successive deduction. It was however a grand conception, and so far very near the truth, that the universe is governed by simple laws; that there is a beautiful order and regularity, even where there is seeming confusion; that there is permanence and stability even where there appears to be flux and change. But it was in their method of attempting to account for phenomena, and discover laws, that the bent of their minds led them astray. A philo-

Led to mistakes.

Though not far from the truth.

sopher must take, so they thought, high 'a priori' ground, he must see from the nature of things the laws which govern natural phenomena, and not be tied down to the drudgery of careful examination of these phenomena, in order to discover these laws: he must make his laws first, and persuade everything to bend to them, and not by careful comparison of particular occurrences lead to the law by inductive generalization. The reasoning by which they attempted to establish the laws they enunciated, was of the loosest and vaguest description. An accidental verbal analogy, or expression admitting of double interpretation, was sufficient to found an argument upon for the coincidence of two ideas with similar verbal representation. The manner in which Aristotle attempts to prove the world to be perfect, will serve as a specimen of this. The bodies of which the world is composed, are solid, and therefore have 3 dimensions, (length, breadth and thickness); now 3 is the most perfect number; it is the *first* of numbers, for, of *one* we do not speak as a number, of *two* we say *both*, but 3 is the first number of which we say *all;* moreover it has a beginning, a middle, and an end. The inference from this is that the number 3 is perfect, and that consequently the world being in three dimensions, is perfect too.

Looseness of early deductive reasoning.

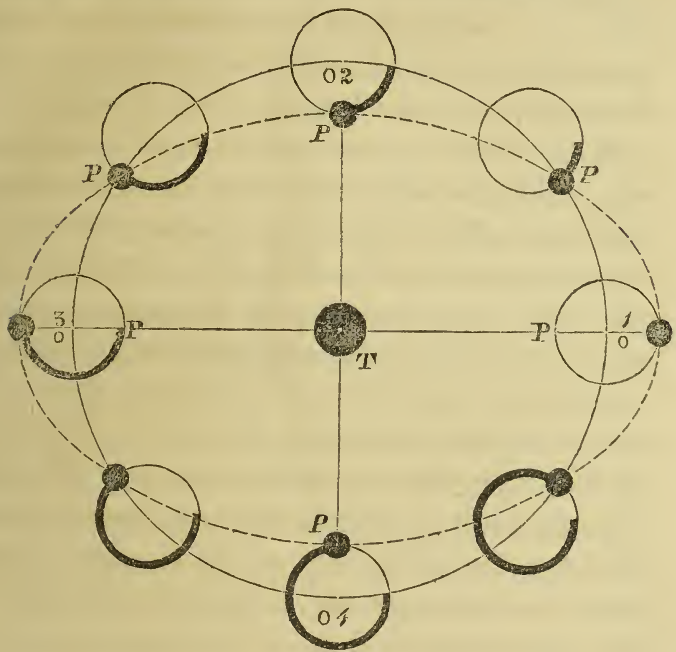
Illustration.

De Cœlo, i.7.

Again, some of them asserted that the motions of the heavenly bodies were circular, and could not be otherwise, for circular motions are the only ones that reproduce themselves; the heavenly motions reproduce themselves; therefore these motions are circular. Now in this simple case it is easy to see the utter insufficiency and vagueness of such reasoning. What is reproducing itself? Is it necessarily true, and if so, how can it be proved, that circular motions are the only ones that recur to their original circumstances? Again, does observation establish the assertion, that the heavenly motions are reproduced and are circular? On the contrary, the roughest observation shewed that circular motion would by no means explain the real state of the case, and a little more careful examination proved, that, as far at least as each revolution was concerned, the motions of many of the heavenly bodies, was not what they called reproduced. This however was not enough to produce a refutation of the theory; with considerable ingenuity they tried modifications by applying a combination of circular motions to explain the observed phenomena, that at times a heavenly body (I am now speaking solely of a planet,) appeared before or behind its place on the circular theory, and also at times nearer than at others.

Illustration.

The nature of some of these modifications may easily be understood from the diagram.



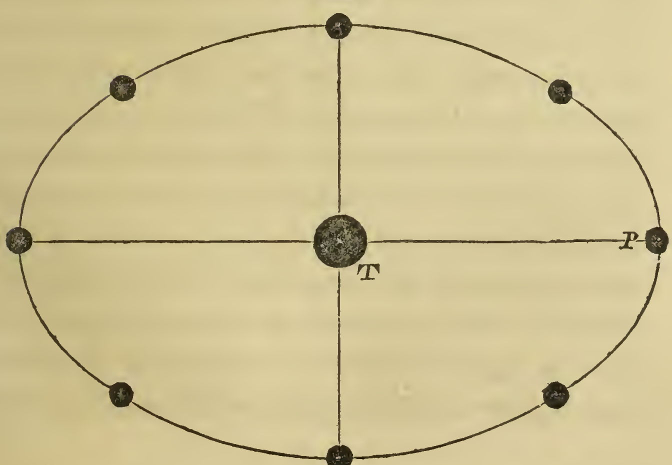



Illustration of combination of circular motion.

If P moves in a small circle, whose centre O moves in another large circle about T, and both P and O go round in the same time, P may be made to move in a kind of oval, T being in the centre of it, and in a like manner ovals could be contrived, which should have T nearer to one side than the other. You can imagine the motion by conceiving a ball tied to a hoop with a string, and made to move in such a manner, that the string shall always be stretched, and the ball go round in the same time that the hoop does. Or thus, imagine a man O, holding a lamp P in front of him, to travel in a circle turning all the while in such a manner that at the several stations, O1, O2, O3, O4, he shall have his face alternately, from, and towards the observer T; the path of the lamp would be an oval. All manner of similar artifices were tried, and circle added to circle, as observation made further correction necessary, and in fact the system of the ancients became so excessively complicated, that the wonder would seem to have been that the very complication to which their system led, should not have led to doubts of its truth, since they started with a full belief of the simplicity of natural laws. And here to guard against mistakes, let us observe that we are not finding fault with them for making

and examining the hypothesis of circular motion to explain celestial phenomena; some assumption must be made, and this was perhaps a more obvious and likely assumption than any other, but it is with the spirit, that put *must* in the place of *may*, that would not tolerate any other hypothesis, that supposed that it had laid down a law which must of necessity be true, and that all nature must bow to that law. In other words, that nature must be made, whether she would or no, to comply with laws which they had proven by arguments, now puerile, now absurd.

Illustration.

We may also take this example which Galileo has furnished to illustrate the points mentioned above, the determination to *deduce* continually conclusions more or less true or absurd as the case may be, from premises more or less true, generally less, and by reasonings more or less fallacious, generally more. Thus assuming the heavenly motions to be circular, their reasoning to prove that therefore the heavens themselves were incorruptible and immutable, might be something like this. Mutation signifies either generation or corruption, but generation and corruption can only happen between contraries. Now there are only three motions;—to a point, from a point, and round a point: but to a point and from

a point are contrary motions, therefore motion round a point has no contrary, therefore circular motions have no contraries; and the heavenly motions are circular, therefore heavenly things have no contraries, and therefore no corruption, and so forth. It is enough to remark that this is utter nonsense, but it will serve well enough as a specimen of loose assumption, and loose reasoning, of vague use of words and uncertain ideas, employed to demonstrate a foregone conclusion.

Galileo Sys. Cosm. Dial. 1. p. 30, quoted by Herschel, Nat. Phil. p. 110.

It would be utterly impossible to mention many of the dogmas of the old School of Philosophy on Physical Science, nor would they be interesting to my audience. I will therefore content myself with two, one in Mechanics and the other in Hydrostatics, as specimens of their quality in general. It was asserted that if one body were twice as heavy as another it must fall twice as fast, if three times, three times as fast, and so on, and the reason assigned was, if one body be heavier than another there is more downward *force*, and that must make the descent quicker. It never seemed to have occurred to any one to make the experiment, and when Galileo, in later times, at the leaning tower of Pisa, made the

Examples from Mechanics.

trial, it was with the utmost incredulity that the then upholders of the old system, witnessed his experimental proof of that which we all know so well, that all bodies, whatever be their weights, will fall to the earth with the same speed, the resistance of the air being the only cause, why a guinea and a feather let drop together do not arrive at the ground at the same instant.

This reminds me of a story which illustrates well enough the absurdity with which men of too theoretical a turn of mind are apt to regard a simple question when they despise experimental verification. The following question was proposed to a set of savans, my memory fails me as to the locality :—

Illustration of unpractical Philosophy.

"If a butt of water of a certain weight have a live salmon put into it, how is it that it weighs no more than before, but that if the salmon be dead the weight is increased." After much discussion, and several learned and elaborate answers had been prepared, it occurred to one more sage than the rest to say "try it." Of course the result was that the weight was increased by that of the salmon, whether it were alive or dead. But to return—their notions on the subject of Mechanical Force were of the vaguest, most confused description; they had no conception of the difference between force as

used to produce motion, and force used to keep bodies at rest, and with respect to velocity and motion itself their views were by no means clear; and their other mechanical laws were no truer or more useful than the one we have given.

Example from Hydrostatics.

The law in Hydrostatics which we now proceed to notice is not a glaring one in absurdity, but one of the best of their dogmas, inasmuch as there was enough of verification of it to make it by no means improbable. In fact, as far as their knowledge went, it was by no means a bad hypothesis. It is this, "Nature abhors a vacuum." This law was an approach to a scientific one, it was wrong, but still the reasons for it were better than those they usually had, and the method of establishing it something approaching the true one. By it could be explained suction, as it is improperlycalled, of various kinds, the action of bellows with their spouts immersed in water, the action of pumps, the fact that a column of water or other fluid may be sustained in an inverted vessel, and other phenomena of this class. These were thus generalized or reduced to follow a uniform law, and if such a law happened to be true it would most certainly explain the phenomena. It was by no means a very violent assumption that it was a law of Nature, that there should be no vacant

space so long as it was possible for substance to fill it, and until experience or experiment shewed the contrary, it was as good a theory as any other.

Indeed the notion of fluid pressure is a very difficult one to grasp fully, even when it is clearly explained, and to find it out was a task worthy of the great men who discovered it. I am afraid that few of those who refer all the occurrences I have mentioned to their true cause, the pressure of the atmosphere, could give any very clear explanation of the how.

We shall see presently by what kind of proof the true theory was established in this as well as in other cases. For the present we see that some of the old dogmas were absurd, depending for their proof on nothing but men's arbitrary fancy, not borne out by facts, and in some cases not even submitted to the ordeal of experiment; that others were somewhat more satisfactory, having a semblance of demonstration to prove them. But we may regard it as the distinguishing feature of ancient Philosophy, which tainted all the attempts made by Philosophers at Physical Science, that a theory was to them the more beautiful, the more free it was from the debasing and trammelling disturbance of verification. That was most to be admired which was too beautiful for men to wish to interfere with, too abstruse for

men to cavil at, too deep for the vulgar at least to understand. Science, whether mental or physical, was too lofty a thing, too noble in itself, to have anything to do (so they thought) with the life, comforts or practice of man; it was to raise man to be akin to Deity, not to teach him to live and act as man. However much there may have been of beauty and of truth in some of these views, as far as Physical discovery was concerned, such a tendency of mind was most vicious in its effects, having the end of leading men to despise the only true and safe method of discovery,—yet had they noble views of the dignity and beauty of Knowledge, and the sublimity of Science, and so much is there true and good in their conceptions, so much of mental acumen and ingenuity in their researches, that it is almost with regret that we are obliged to confess the inadequacy of their methods, and in Physical Science, at least, to compare them to the Philosopher Thales, who contemplating too earnestly the stars, fell into the water. On which has been shrewdly observed, if he had looked in the water he might have seen the stars, but looking at the stars he could not see the water.

Inadequacy of ancient method in Physical Science.

How much to be admired in some respects.

Plato says: "An astronomer must be the

wisest of men; his mind must be duly disciplined in youth. Especially is mathematical study necessary, both an acquaintance with the doctrine of numbers, and also with that other branch of mathematics, which, closely connected as it is with the science of the heavens, we very absurdly call *geometry*, the measure of the earth."

Plato, Epinomis, pp. 988, 990.

Summary of advantages.

We may then conclude that we are indebted to ancient philosophy for these benefits:

1. Considerable geometrical knowledge.

2. A strong belief in the importance of the deductive method of establishing a science, when first principles of it are known.

3. When certain phenomena recur in regular order, we may infer that they proceed from some determinate law, which must be guessed first, and verified afterwards.

It is in the reducing to order the processes implied in this last law that later discoveries have made so many advances,—the manner in which observations must be made to suggest a probable hypothesis, and the manner in which the verification or rejection of the assumed law is to be carried out; for in general the guesses of philosophers were very wide of truth, and verification was by no means indispensable in every case.

We will now proceed to trace briefly as we are able, how it was that science learned to throw off the trammels, with which a blind adherence to Aristotelian teaching had shackled it, to be taught that, as Herschel so well puts it, "The liberty of speculation which we possess in the domains of theory, is not like the wild license of the slave broke loose from his fetters, but rather like that of the free man who has learned the lessons of restraint, in the school of just subordination."

Hipparchus.

One of the first, and by far the most distinguished, of those who early perceived the importance of laborious verification of laws by experiment, was Hipparchus. He devoted himself to the study of astronomy, and the problem he proposed to himself was to account for the celestial phenomena on the hypothesis of circular motion—that is to say, to represent geometrically such motion, not to give any reason for it, such as attraction. The first thing to be found out was evidently, how did the heavenly bodies move, or appear to move. A much later problem would be, why do they do so? The laborious observations that he made, wonderful for their accuracy, (when we consider the nature of the instruments with which he worked, no telescopes, no transit instruments,

no mural circles, not even a clock; instruments so indispensable to the observer,) are of the greatest value now; and the geometrical representation of the motions he observed, complicated and ingenious as they are, are in reality, as far as they go, statements of the results which later theory has established, the actual form in which modern analysis has thrown the solution of the problem of the Lunar and Planetary motions. He really laid down a method of representing actual appearances, as far as his observation went, although no progress was made towards the discovery of the law which was the cause of such motions. Hipparchus left the science of Astronomy enriched with a number of most valuable observations, and an explanation of some of the heavenly appearances; he also left data, as he himself tells us, for the use of later philosophers on certain planetary motions which he himself was not able satisfactorily to determine.

Whewell, Hist. of Ind. Scien., p. 195.

The next name of note to which we shall allude, is that of Ptolemy. His work consisted principally of arranging and correcting the observations and results of previous astronomers, and to him is due a complete statement of the History of Astronomy at his time. He made also some important discoveries, and

Ptolemy.

set forth plainly what is called the Ptolemaic system of the motions of the planets. He placed the earth in the centre of all the planetary motions; the sun and all the planets were made to revolve about it; and by the aid of artifices like that alluded to above—that is, by various combinations of circular motions—he gave a very fair explanation of the different planetary motions. This theory is now too much decried as absurd, and it is asked why so much more complicated a system was not earlier replaced by the simpler one, with which every school-boy is familiar, which makes the sun the centre of all the planets' motions.

His Theory.

It must be remarked that it is very difficult to grasp fully ideas contrary to experience, still less to make a theory in direct contradiction as would at first seem of the evidence of the senses. It was hard to believe that this earth vast as it appeared, should be in rapid onward motion and rapid revolution about its axis, while the sun which seemed to move, and of whose size they had little means of judging, was stationary. Again we must remember that there were really strong grounds for accepting the theory of another and more satisfactory kind. Eclipses could be predicted by it, as well as by the later theory, and for rough observation, with equal precision.

Reasons for it.

Also we must recollect that the theory of the earth's motion appeared inconsistent with the fact that the stars preserve always the same apparent place with respect to the earth. It was but natural to suppose, that if the earth moved in an orbit, it would seem sometimes nearer and sometimes farther off, and that the stars would not appear always the same distance from one another; just as in walking round a field, trees anywhere near the field would look differently placed according as you went nearer or farther off from them. If the trees were very far off, this difference would not be so evident. It was not easy all at once, for men to satisfy themselves, that the stars were so very far off, that not only the size of the earth itself, but of its orbit, which is 190,600,000 miles across, was very small compared with their distance, so small that it made no difference where in its orbit the earth was. Another reason was, that it was proved that Venus and Mercury must exhibit phases like the moon if the sun were really the centre of planetary motion, and no such phenomena had been observed as yet. There was then good reason for retaining the Ptolemaic Theory until it could be shewn that another would explain the planetary motions more simply

andmore accurately, and also answer satisfactorily the reasons brought against it.

Copernicus was the man who had courage and talent enough to defend the solar system which we now receive; for in those days (early in the 10th century), it required no little courage to attack notions and prejudices of long standing, and which Divine and Philosopher were prepared to defend.

Copernicus.

Those opposed to Copernicus were rather the latter than the former, for the religious opposition to the new discoveries which were said to be opposed to the scriptures, had not yet taken any decided part. But for centuries past the labours of all, with few and honourable exceptions, who had any pretensions to learning, had been restricted chiefly to transcribing and commenting, and bigotry was the order of the day, any who presumed to attempt to overset the established opinion were persecuted with the most deadly hatred, as the poet has happily said—

They stand
Locked up together hand in hand,
Every one leads as he is led,
The same bare path they tread;
And dance like fairies a fantastic round,
But neither change their motion nor their ground.

Quoted by Whewell, Hist. Ind. Science.

Copernicus and his pupils however held their ground, and soon afterwards the discoveries of

Galileo, afforded the most wonderful verification of the system of Copernicus. By the discovery of the telescope he was enabled to shew not only that the planet Jupiter with his moons, was, as it were, an epitome of the solar system, but that Venus shewed the phases which objectors had asserted must be the case, if the earth as well she, revolved about the sun.

Galileo proves Copernicus' system.

Galileo was hence enabled to confirm Copernicus' Theory of the solar system, in a most satisfactory manner, though he had to endure a still larger share of persecution on account of his opinions, than Copernicus had. As yet the cumbrous geometrical machinery which the system of circle upon circle had introduced, remained untouched; it was reserved for the intellect and perseverance of Kepler to discover not merely as Hipparchus had done, a way of representing *nearly* the motions of the planets, but one which should exactly and simply represent their actual motions. Instead of being satisfied with the old system of epicycles, which were both complicated, and, with the improved powers of observation, by no means accurate, he tried innumerable other hypotheses; his works are especially valuable, not only on account of what he discovered, but also by shewing wherein he failed,

Kepler.

for he has preserved records of both successes and failures, with equal fidelity and almost equal affection. After years of toil spent in examining his various guesses, he at last announced his great discovery that the planets move round the sun, in curves called ellipses, like that in the figure; (the properties of which curve had been well known to the ancients,) the sun being not in the centre, but in a point called the focus, rather nearer to one end of the longest diameter. He also discovered laws about the time of the body in its path, and the area which it swept out about that point; which however simple when discovered, were hard enough to guess simply from observation. These laws, guesses at first, among innumerable wrong guesses, were established by induction, that is by long and laborious trial, observation, and comparison of results, and were the first great steps made in the science of Astronomy. Thus the old complicated system was replaced by one simple and beautiful, and the taunt expressed by Alphonso Castile, that if he had been consulted at the creation he would have contrived the universe on a simpler and better plan, fell to the ground. Nothing however had yet been done to explain the reason of the motion, of which the circumstances were now determined.

His discoveries.

Upset the old system.

Philosophers had busied themselves entirely with the *how*, and had not attempted the *why*; those that is, who with clear views of the only safe way of making discovery, objected to accept absurdities on the dictum of others. They had used the inductive process of verification to some extent, but without precisely knowing the power of the agent, with which they worked.

Lord Bacon.

Francis Bacon reduced to a system, the method which he set forth with the utmost confidence as the only one adapted for the prosecution of discoveries in Physical Science, for arriving at Physical laws, no less than explaining Physical facts. It was reserved for Newton, he whose name stands foremost in every department of science, to establish the physical cause of heavenly motions. Others had fancied that the cause of planetary motion was attraction to the sun. Milton even has:—

Newton.

> "What if the sun
> Be centre to the world, and other stars,
> By his attractive virtue and their own
> Incited, dance about him various rounds."

Some had observed that the attraction must be less, the further off the body were, and had even suggested the true law, as a guess; or from vague reasoning, that, if it were anything like light, poured forth from the sun, it must of ne-

cessity, from geometrical considerations, follow such law. This law is called that of the *inverse square* of the distance. You may understand what it means in this way: Suppose a body placed at a certain distance from the sun, it would be pulled towards it with a certain force; if put at one-half the distance, it would be pulled with four, *i. e.* twice two times as much force; if at one-third the distance, with nine, *i. e.* three times three times as much force; if at one-fourth, with four times four or sixteen times as much force; and so on.

To Newton fell the task of verifying this law in the fullest possible manner. He first endeavoured to shew, that the moon was retained in her orbit by the attraction of the earth; and, though foiled once by having taken the erroneous measure of the earth then in use, he was enabled in the most triumphant manner to verify it, when the more correct measure was afterwards put forth.

Discovers gravitation.

With a surpassing intellect, to which we cannot but accord most unbounded admiration, he invented methods of calculation first, and solved the problem of the moon's motion in two ways. He shewed that if the motion of one body attracted by another, be such as Kepler had observed, it must be because it is

Explains fully moon's motion.

attracted in the way mentioned above; and he also shewed, that if we suppose the attraction of one body to another to be according to this law, the motion must necessarily be such as Kepler had observed. He also proved Kepler's other laws by his process. Thus, then, the observed motion will give the physical law which is the cause of it, namely, the attraction to the centre. Or, reversing the question, the assumed law will give motion in accordance with observations; and each of these propositions may be regarded as a proof of the other, just as a multiplication sum will prove a division, and a division sum a multiplication. Nor was this all. The sun attracts the moon in a similar way, though not nearly so much as the earth does, because it is so much further off; but it attracts it enough to draw it a little from its orbit, sometimes one way, sometimes another. Newton applied his method with success, to explain and compute these variations, inequalities they are called, in the moon's motion.

His method, beautiful and wonderful as it is, required the intellect of Newton to use it: with his method no one up to the present day has done anything further. Clever men can just read and understand his works, and that is all.

New methods needed.

As Whewell strikingly remarks, "The ponderous instrument, so effective in his hands, has never since been grasped by one who could use it for such purposes; and we gaze at it with admiring curiosity, as on some gigantic implement of war, which stands idle amongst the memorials of ancient days, and makes us wonder what manner of man he was who could wield as a weapon, what we can hardly lift as a burden." The need, however, produced the processes required; for in science, as in other things, the demand produces the supply. Newton's method had been strictly founded on geometry, but geometrical methods were no longer enough; the gigantic implement was replaced by more penetrating and more subtle instruments; the battle-axe, so to speak, was replaced by the rifle. Mathematicians invented new methods of calculation, and mathematical analysis by which, when Newton had shewn the way, the problem of the moon's motion has been still more completely determined,—methods by which symbols are made to think for us, as it were, and mathematical processes represent the intense thought, which was too much for the mind of man; and by these means all Newton's and many other problems can be easily and accurately solved. National jea-

New methods of analysis invented.

lousy, too, played its part in the cause of science, and caused the Newtonian theory to be subjected to the most searching tests, from the shape of the earth, the motions of pendulums, the disturbances of the heavenly bodies, before it was universally accepted. Suffice it to remark, that it rests on the firmest footing of inductive reasoning that is possible to conceive.

Discovery of Neptune.

And in taking leave of this very hasty and imperfect sketch of the discovery and verification of the theory of gravitation, we cannot avoid alluding to a well-known and most extraordinary instance of its verification, the discovery of the planet Neptune. If the attraction of gravitation be universal, and the planets move round the sun under the action of his attraction, they must draw one another slightly from their orbits round the sun by their attraction of one another. The calculation of the amount of this disturbance is difficult enough when the attracting body is known, but to calculate the magnitude and position of an unseen and unknown body, merely by its disturbing effect on another, was a problem that might well terrify the most accomplished mathematicians. This was, however, done in the case of the planet Neptune. The observed place of the planet Uranus disagreed with the calculated place by

a small, though in the present state of astronomic science, appreciable amount. It had been supposed that an unknown exterior planet might produce this effect, and from the difference between the computed and actual places, Adams and Leverrier, about the same time, calculated independently the orbit and place of the new planet and directed observers where to look for it. The planet thus predicted was observed by Professor Challis at the Cambridge observatory in England, in the place which Adam's had assigned, twice before it was recognized in Berlin by Dr. Galle, who was searching according to Leverrier's directions; but the foreign astronomer had the good fortune to be the first to pronounce the observed star a planet; the glory of the discovery is, by general consent, divided between these distinguished men. This instance is one of the most striking that could be adduced, to exhibit the advance of astronomy in theoretical development, and practical application; the mathematician, the observer, the instrument maker, almost equally indispensable; it illustrates the immense strides that deductive science had made in the department of purely mathematical analysis; it furnishes an additional proof of the Newtonian system of

Main's Astromy, Weale's Series. p. 134.

gravitation, and it adds its quota of praise to the combination of theory, experiment, and mechanical skill, that go to the formation of good astronomical instruments.

We must endeavour to notice a few illustrations of a more generally interesting and intelligible kind, but it was impossible to say anything on the union of experiment and theory, and not dwell more or less at length on the science of astronomy, even at the risk of being to some extent tedious; since it is the most perfect exemplification of the beauty of the inductive method of verifying laws; of the importance of geometry; and also of a point on which little has yet been said, the importance of practical excellence in the formation of instruments. Let us, in passing, observe on the connection between theory and practice in this. It

Theory and practice in instrument making.

is known that light, in passing through glass, water, or other transparent substance, is separated into various colours. Careful experiment furnished the law of separation, and mathematical calculation based on this, pointed out how to take lenses made of proper material and of proper powers to remedy the defect produced by this colour, in the picture presented to the eye, when the lenses were used for the formation of tele-

scopes. Again, experiment showed that light travels in straight lines, which, by reflection or refraction are bent after certain laws; these laws were subjected to careful experimental proof, and then theory showed the best form of lens to be used, in order that the picture formed by them might be as distinct as possible. Theory having furnished the conditions of a good lens, mechanical skill came into play to carry out its suggestions; so that a good telescope cannot be obtained without careful experiment, theoretical calculation, and a careful and skilful artizan.

Archimedes.

And now let us revert to the simple laws of mechanics and hydrostatics of which we previously took notice. Archimedes had in very early times arrived at just views of some statical questions, and even the fundamental property of fluids; this knowledge, however, was but of the individual, and had long been forgotten; everything had to be discovered over again. Galileo shewed the absurdity of Aristotelian notions with respect to force and motion, and by careful experiments made on bodies sliding down inclined planes, which, moving slowly, could be easily observed, made considerable advance towards clear views on these matters; he also

Galileo's mechanical discoveries.

shewed that bodies fall with the same speed, whatever their weights.

Among other discoveries which he made, one of the most remarkable, and most valuable, is the common pendulum, which will afford our next illustration of the union of theory with experiment. Observing the oscillations of a lamp in a cathedral, he noticed that, however much or little it swung, it performed its oscillations in the same time. Experiment convinced him that his observations were true, and clocks constructed to count the oscillations of a pendulum became very accurate registers to measure time. So far, it was independent of theory. But soon it was shewn by calculation, that, if the force of the gravitation of the earth on a body continued always the same, then the regular beat of a pendulum was a necessary consequence. This, then, is most important. Experience tells us that clocks keep time more or less correctly, according to the perfection of their mechanism. Theory shews that this is necessarily the case, and leads us to attribute trifling deviations to nothing but defective mechanism, or inevitable disturbance (slight, though it be) by the resistance of the air. Or to view it in a different aspect; if we assume the regular beat of the pendulum to be a fact es-

Pendulum.

Theory and experiment.

tablished by observation, we obtain a proof of the constancy of the tendency of bodies to the earth i. e. that bodies weigh the same always at the same place. Nor is this all, the force of gravity regulates the *time* of the beat; Theory tells exactly how the time and the force of gravity are connected by a simple formula. Suppose then that pendulums of the same length do not beat the same at different places on the earth, the inference will be that gravitation to the earth, the same at the same place is different at different places; for example, will shew that a body weighs less at the equator of the earth, than it does near the poles. And this enables us to prove the rotation of the earth, to prove what certainly seems otherwise most likely, that the celestial vault with the stars and planets does not turn about the earth, but the earth rotates on its axis, inside it. This, the difference of beat of a pendulum shows in the following way.

Proves rotation of earth.

You know that the effect of making a body move in a circle about another is that it will fly off unless some force to the centre keeps it at the same distance. This tendency to fly off is called the centrifugal tendency. If the earth spin on its axis, a man at the equator would fly off were it not for the attraction of the earth, which is much more powerful than this ten-

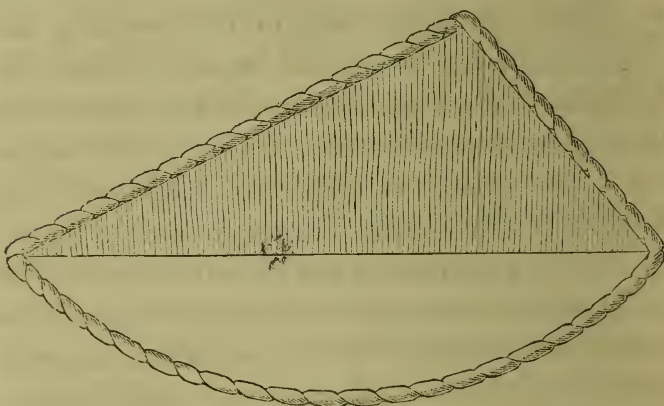
dency. Nevertheless, he will press somewhat less heavily on the earth at the Equator than anywhere else, because the centrifugal tendency increases the farther the body is from the axis. The pendulum oscillation shews as it ought to do, that the tendency to the earth is less at the equator than elsewhere. Or again, reversing the question; assume the rotation of the earth as an experimental fact, we have at once the means, by somewhat refined calculations, of finding how far the equator is from its axis, and by a series of organized experiments at different parts of the earth for determining its figure. And all this follows from Galileo's observed law of pendulum motion, and the theoretical proof that his law was correct. It is possible to measure arcs of the earth in different parts, and thus determine its shape; the result is that its shape deduced from the measurement, agrees well with the results from pendulum experiment.

And determines its shape.

Not long after Galileo's discovery of the pendulum, so important in its results, Stevinus made a simple and elegant discovery, on which the whole science of statical mechanics may be made to depend. Suppose an endless string hung over a smooth double wedge, with its base horizontal. It will remain at rest, and evidently will do the

Stevinus' statical discovery.

same if the loop below be cut off, because the tendency of the loop to pull it round one way, being the same as that to pull it the other, the loop may be removed. Hence the strings lying on the two sides balance, i. e. weights which balance one another on inclined planes, are proportional to their lengths.



Hydrostatical law established.

We have mentioned the overthrow of the supposition that nature abhorred a vacuum, and have asserted that the pressure of the atmosphere, was the cause to which all the phenomena attributed to the above were to be referred. It was found that a pump would not raise water to a greater height than 34 feet, so that nature had no objection then, to tolerate a vacuum above the water. Torricelli made an experiment with a column of mercury, and produced a vacuum above

Torricelli, Descartes, Pascal.

it at a smaller height; the vacuum which we have often seen in a barometer tube. Descartes previous to this, had attributed the support of a column of mercury to the pressure of the air. This assumption Pascal proved by taking the barometer up a mountain, where the atmospheric pressure was of course less, and found the supported column less than before, by several inches. This fact being once established, hydrostatical science was carried on with a zeal which led to other important discoveries, on which our limits will not allow us to enlarge.

Whewell's Hist. of Ind. Sciences, vol. ii. page 67.

We have mentioned one or two cases in which early science made use of laws for the explanation of phenomena, which, however untrue, were yet not violently absurd; which in fact, were good enough as hypotheses; though later discovery overturned them. We must in many cases commence with an hypothesis, and only reject it when we meet with a better. To be able to make a good hypothesis, and examine fairly its truth, are the great qualifications of a philosopher. He must not be so wedded to the productions of his own ingenuity, that he will not reject them if they are not borne out by facts. He will imitate Newton, who rejected for a time his own wonderful discovery of

Qualifications of a Philosopher.

gravitation, because of a slight numerical discrepancy in the result, a discrepancy so slight that many would have made it of no account. He will be like Kepler, who rejected one ingenious explanation of planetary motion after another, on account of trifling difference between his theory and the observations applied to test it. And not like the servile commentators on Aristotle, who indignantly rejected any statement, at variance with the dicta of the great master; and in order to support his theories from rude interference, clothed them in language more and more ambiguous, reducing science to be the art of talking unintelligibly on subjects of which we are ignorant.

We are about to notice an extraordinary case in which rival theories seemed for a time almost equally probable; explained the circumstances of nature to some extent with equal accuracy, and with equal inability to account fully for all phenomena. Optics as we have observed before, may be made to some extent a geometrical study. But there are certain phenomena which it seems impossible to explain, without knowing something of the constitution of light itself; how it is produced, and why it is that it follows the laws which experiment shews it to do. Newton supposed that light consisted of very minute particles, emitted in all directions from lumi-

Theories of Physical Optics.

Newton's and Huyghen's Theories.

nous bodies, and on this theory explained many phenomena of vision. Huyghens had about the same time imagined that it was produced like sound, by the vibration of a subtle fluid, penetrating all transparent substances. If so, as with sound, the vibration must be in equal times. The pendulum law furnished the law of vibration in equal times for theory to work upon; would this law explain more appearances than the other, the emissive theory of light? At first it would have seemed not. For instance,—if light go through a hole, there is a spot of light formed on a screen placed to receive it, determined by the shape of the hole. This is easy enough to explain if we suppose the particles of light to be shot straight through it; but if we follow the analogy of sound, we should expect all the screen to be illuminated, since sound can be heard in all directions after passing through the hole. Rigid calculation, however, shewed that it was all right; that, if the waves were very much smaller than the hole, as those of light are, which are excessively minute, they would only go straight through. But if at all to be comapred with the hole in size, as those of sound, which are several feet in length, they would spread in all directions after passing through the hole. This theory too, accounted

for the shadows of objects not having defined sharp edges, but gradually fading away as we observe them to do. On applying the test of investigation, they ought to be sharp and distinct on the emissive, but not on the wave theory.

But theory teaches that, if it be true that light is produced by waves, these waves must interfere in certain cases, so that two streams of light actually produce darkness. A delicate experiment showed, however wonderful it may seem, that it is possible to produce darkness by two streams of light. Let us take an illustration; if a stone be thrown into a pond, circular waves spread in all directions. You could imagine another stone, dropped in directly after, so as to make waves which should fall exactly between the first waves and produce still water again. So it is that two waves of light or sound may follow one another in such a way, as to neutralize each other's effects.

Illustration of interference.

This discovery, due to experiment, was a wonderful confirmation of the wave theory, for there is no means of accounting for such darkness if the light were emitted or shot forth, and the emissive theory was therefore at fault.

Also, theory shewed that, if light were the result of waves, there must be a bright spot in

Shadow of Sphere.

the middle of the dense shadow of a sphere; this bright spot may actually be seen if the experiment be carefully made; another wonderful confirmation of theory. To take another illustration; Newton had observed that, if two pieces of glass touched, which were slightly curved, there were brilliant rings of various colours about the spot of contact, with black rings between. The utmost that the emissive theory could do in explanation, was to assert that there might be, between the bright rings, rings only half as bright; the theory of waves shewed that the rings must be quite dark. Experiment gives black and not half bright rings. The various extraordinary and beautiful phenomena of what is called polarized light, are on the whole consistent with the undulatory, and inconsistent with the emissive theory of light. Time will show whether any other theory may arise, which offers a better explanation of all the appearances. For the present it must be considered almost certain, that, if the right theory be not now laid down, the true one is but some slight modification of it.

Newton's rings.

Polarization.

We have hitherto dwelt chiefly on the more abstruse discoveries, for the prosecution of which a very considerable degree of know-

ledge is actually necessary. It were hopeless to attempt to pursue the law of gravitation into its inevitable consequences, establish the stability of the Solar System, and account for the various departures from the first broad statement of results, as has been done by Clairault, D'Alembert, Lagrange, Laplace and others, too numerous to mention; or even to follow the investigation of others in these matters, without considerable natural ability, and considerable mathematical skill. In respect of the theory of light, the same observation holds good. But there are no sciences in which the value of the *inductive* and *deductive* is more fully brought out; and therefore, at the risk of being tedious and obscure, I have dwelt on them somewhat at length, since they show how the experimental proof suggests the theoretical, the theoretical paves the way to further convincing experiment.

Astronomy, etc. necessarily abstruse.

We will now notice other branches of science to which a knowledge of mathematical processes is not so indispensable. The Science of Chemistry is one that plays a most important part in the industrial sciences and arts, and in its various ramifications in the science of Life, and the well-being of mankind; yet the laws which govern

Chemistry, theory entirely the result of experiment.

its operations are as yet to a great extent unknown, while those that are known are entirely experimental. It is beyond almost all others a science of numbers, and proportions, and exact quantitative distribution of elements. Its theories admit of proof by there being always an invariable result, from performance of the same operations. There would seem to be fewer disturbances, fewer apparent exceptions to its laws, and no special mathematical learning is required, either to predict the circumstances of future, or account for those of past experiments. Experiment will give the laws of combination, the exact proportion of ingredients that goes to the formation of natural compounds of elements ; and exact quantitative analysis is one of the most beautiful and useful results from this knowledge, a knowledge which none need despair of obtaining. The theories of Chemistry are of a simple and easily applicable kind, which do not even demand intense concentration of thought. It is therefore, one of the most popular as well as useful of studies—by its aid the secret poisoner cannot hope to escape the hands of justice—the scarcely less deadly assassin, who for a small profit adulterates our food and poisons our drink, is detected in his nefarious proceedings. By its aid the languid pulse is restored to vigorous ac-

tion, the diseased system to health; and if we include under the designation of Chemistry, the various branches of experimental philosophy, we may add: by it, is the miner enabled to descend with safety into an atmosphere as inflammable as gun-powder—by it, is the soil rendered more fertile, and the destructive insect no longer able to carry on its ravages—by it, is the mine ventilated and rendered wholesome—by it is the lightning conveyed harmlessly to the ground.

Medical Theories inductive.

The science of Medicine is of itself a most ample illustration of the good and evil of inductive generalization. From the days when mens' surgical skill enabled them to bind up a wound with healing herbs, to the present day, has the healing art been one especially venerated and cultivated by mankind. Savage tribes treat the pretenders thereto with reverence; civilized races shew their willingness to be relieved from the ills that flesh is heir to, by swallowing potions which they half believe will completely remove every disease, pain, or annoyance. Yet the laws of healing are entirely experimental. Observation, keen quicksighted observation, puts a man on making experiments to verify his suspicion of the efficacy of a certain remedy. The instinct of animals, points out the virtues of this or that herb. Science finds out

the method of extracting the virtue, and leaving the useless portion behind.

Discovery of quinine.

Take an instance or two,—a man grievously afflicted with ague, is forced by necessity to drink the bitter water in which some trees are lying; he recovers: the cure is traced to the properties of the water, and thence to the bark of the trees. From this bark science extracts the quinine, known as a specific for ague.

Discovery of iodine.

A soap boiler finds in his vats a substance which corrodes his vessels, and which is different from any substance before known. The analysis of this by a scientific chemist produces one of the most singular and important chemical elements, iodine. Its presence is traced to the ashes of sea plants used in the manufacture; to the sea water itself, and other marine products, among others, to sponge. Dr. Coindet of Geneva remembered that burnt sponge had been used as a remedy for goitre, an unsightly glandular enlargement to which the mountaineers of Switzerland are especially subject. He thought of trying its effect on those thus afflicted, and the result is the discovery of the most efficacious remedy for all such affections.

Herschel, Nat. Phil., page 51.

Such are some of the ways in which discove-

ries are made. Experience or experiment are the only implements with which chemical science works; it is from experience only that we know what will be the effect of putting a lump of sugar into water, of burning a stick in the fire, of mixing various colours, of the combining of elements. And philosophy teaches us that nothing is lost or dissipated. A philosopher would deduce the weight of the smoke from the coals consumed, and the ashes left; while an ordinary observer would imagine a loss of that consumed. We have then arrived at a class of sciences in which the deductions are simple, while the experimental processes are as boundless as nature herself. It is possible for a man, having no other ideas than those of space and motion, to reason out for himself all the propositions of geometry, and, having arrived at the laws of motion, solve for himself the motion of bodies under any conceivable law, whether such law exist in nature or not; the only limit being the limit to which he can carry his deductive processes; but he cannot reason out, that lemon-juice is a specific for scurvy, or that blue and yellow powders mixed will appear green to the naked eye, but blue and yellow mixed, under a microscope.

Difference between chemistry and pure and mixed mathematics.

Before concluding, we must allude briefly to a class of sciences, or more properly empirical arts, which are still more dependent on experiment than any strictly natural science, of which the laws are simple and determinate, and capable of being followed out into their results. It were next to impossible to find anything more uncertain than the duration of human life, and any calculations based on it would seem at first to share in this uncertainty. It is however possible, by very careful collection of instances, to reduce the uncertainty to mathematical value. On the whole, averages are nearly the same; the average height of thermometers, barometers, etc,, are more and more nearly alike, the longer the successive intervals of time, the greater the number of instances collected, and so it can be settled as a fact, quite accurately enough to reckon upon, that a man's life in a certain country, under certain circumstances, is worth so many years' purchase, and that by paying into a common stock a certain sum annually, a man may insure to his family, if he be called away by death, a certain provision. But yet in the various cases that may occur of life annuities, insurance for a limited number of years, insurance on the joint lives of several individuals, etc., problems occur

Theory and practice in life assurauce.

of very considerable intricacy, and requiring very considerable mathematical skill to calculate the fair amount of contribution; that individuals may not pay more than is necessary, or companies be ruined by insufficient subscription. Accordingly respectable offices grudge hardly any salary to secure the services of a first rate mathematician, on whose reasoning from the given data they can rely. Here again, in a simple practical matter, is theory absolutely necessary to enable the practical matter to be carried out fairly and safely.

Political economy almost an experimental science.

Political economy is another of these arts, which men are learning but by slow degrees. If it be no longer true that nations do not learn by experience, the laws of government, supply and demand, taxation, military strength, and legislative enactments, are being but by slow degrees arrived at.

Meteorology.

Some Physical Laws are still waiting to be fully elucidated by the searching test of careful experiment, and a series of tabulated observations. Such are the laws of the direction and force of magnetic currents in the earth and their physical cause, of meteorologic phenomena and storms, and cli-

matology, in which investigations our own Canadian observatories are playing their part.

As a last illustration of the manner in which such laws are discovered, I will direct your attention to a case in which what has been observed, may or may not lead to a discovery.

**Possible future discovery.** The magnetic current, that which directs the needle to the pole, is subject to variations both in intensity and direction. There is one such variation that takes a period of ten years to go through all its changes and recur to the original circumstances. Now it was observed that certain changes in spots on the sun's disc took the same time, ten years, before they assumed the same appearance. Can it be that changes in the sun's spots have anything to do with magnetic currents on the earth's surface? If future investigation throw more light on this, which may be only an accidental coincidence, or may be the operation of a cause producing an effect, it is possible that this observation may aid in determining the cause of the current, or the nature of the spots, or both.

But, ladies and gentlemen, I have already trespassed on your patience too long. If considering my audience to consist to a great extent of persons more or less scientific, I have tried to give too much science, or too many of the

hard terms which make simple ideas hard to grasp; if by striving to be instructive I have not only failed in this, but also failed to be interesting, I would only hope that something which may have been said may not have been said altogether in vain. In conclusion of this review of my subject, in which I am conscious that the more interesting topics have been more hastily dismissed, and that much has been omitted that might have been said, let me warn you that mighty as is the power of the inductive method to discover truth, it has its dangers if indolently or carelessly applied. The race of man in its infancy fell into error by the tendency to seize too hastily on a law and refine and reason upon it. Being delighted with their new found powers of thought and reason, men could not wait to examine on what basis their reasoning was founded; they forgot that to build high they must dig deep; and were anxious to rear a goodly and ornamental pile, and finish the structure without taking heed to the foundation. And in a practical age, so called, the same impatience after results manifests itself. It is the danger into which a young and progressive people are liable to fall; they cannot bear enough in mind the proverb "festina lente," "hasten slowly," and have patience

Conclusion.

to wait for the results of laborious investigation. They find it hard to stop to gain enough of the theoretical knowledge which will make their practical knowledge useful. A great and glorious future may be opening out before us, but it depends on us now to a great extent how great and how glorious it may be—whether the growth be of a sound and lasting character, or like a mushroom, sprouting in a night.

We live in an age which reverses the old supposition that science has nothing to do with nature or with man. We consider that science may enter into everything rather than be superior to everything. We do not try to prove to men that they are to render themselves independent of the laws of nature, but to render themselves masters of them. Science is like an elephant's trunk, that will pick up a pin or rend an oak. But in order to use this instrument properly, it must be really science, really knowledge, not a vague smattering, not a servile appropriation of the works of others. Every one may be more or less scientific. It is a noble thing to trace the laws of nature, and to rise from the contemplation of nature to nature's God. But let us remember that we shall not be men worthy of the name if we only seek after knowledge for the purposes of sensual ease or pecuniary profit.

This is not the way to be great and noble; this is not the way to secure the glorious birthright of humanity, neither will it compass the end sought. It is only by aiming at something high, that we can achieve at all; only by aiming at perfection that we reach excellence. We can never tell what good to mankind may result from the prosecution of science in any direction. Who would have supposed that the dreams of Kepler would lead to the explication of the laws which govern the universe; that the gropings of the alchemist after gold and an immortal elixir, would lead to the useful and now indispensable science of chemistry. That a shrewd man observing a lamp swinging in a cathedral should by this observation enable us to weigh the earth and determine its shape. Let us not be content with a log shanty when we can build a goodly stone mansion. Men in Canada have eyes and ears, brains and intellects, as well as stalwart arms and manly hearts. Let them put them to good use. Let societies of arts and manufactures flourish. Let universities and colleges do their work in instilling sound theoretical knowledge, and, as far as may be, sound practical instruction. Let each and all keep eyes and ears about them to take advantage of all the opportunities of improvement

offered. The time is *now*, now to lay a solid foundation of the greatness of nations to come.

Who loves not knowledge? Who shall rail
Against her beauty? May she mix
With men and prosper. Who shall fix
Her pillars? Let her work prevail.

FINIS.